Catastrophism versus Uniformitarianism in the History of Star Formation

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Abstract

Several early-literate traditions that have come down to us include some view of star formation. That of the Babylonians (and of the Old Testament Jews which derives from the Babylonian) take star formation to have been a single event, part and parcel with the formation of earth, sun, planets, and whatever else exists. Greek mythology, on the other hand, describes a series of events, deriving from interactions between the Gods and mankind. Egyptian pharaohs could join the stars (presumably happy events), while the Chinese tradition expected changes in the heavens normally of unpleasant purport. This separation of views between "long ago, when conditions were very different" (catastrophism) and "ongoing, hence amenable to study" (uniformitarianism) continued until the middle of the 20th century, and we explore some of the events that led to mainstream opinion switching back and forth and to the gradual convergence to the on-going point of view.

1 Introduction: the earliest views

"Vaya'ass Elohim et shney hamorot hag'dolim..." And G.d made two great lights, the greater light to rule the day and the lesser light to rule the night. "V'et hakochabim." And also the stars..."Vayechi erev, vayechi boker, yom r'vi-i." And there was evening, and there was morning. A fourth day. This, from the King James version of Genesis, makes clear that star formation happened all at once, along with formation of the sun and moon. And, since it happened on the fourth day, clearly a three-day symposium like the present one cannot solve all the problems.

In the Babylonian version a few hundred years earlier (Kragh 2007), Marduk, or Anu, or Enlil, or Ee arranged the stars in heaven, or set fast the stars in place in a furrow (the zodiac, presumably), except perhaps for the bow constellation (part

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of what we call Orion) which might have been formed later. Some of the modern constellations are recognizable in their inscriptions.

Greek mythology, on the other hand, tells us (for instance) that Orion frightened a group of maidens, who ran away for five long years, until Diana, the Moon Goddess, took pity and set them in the heavens as the Pleiades, who cling to the mane of Taurus, while Orion continues to chase after. Add up several myths, and you will come to the conclusion that the Moon was in the sky first followed by the Hyades (daughters of Atlas), the Pleiades, Orion, and Canis Major and Canis Minor, Orion's hunting dogs. Star formation therefore occurred over a period of time, but presumably had ended when gods and humans ceased to interact directly.

Several different drawings of the Egyptian cosmos have come down to us, all with Geb as ground, Shu as air, Nut or Nuit as sky, with Ra sailing his boat across the heavens, sometimes above the stars (which are five pointed like ours) sometimes below. The initial process was Shu prying sky away from earth (a bit like the Chinese mythical giant, Pan Ku, growing at some tremendous rate until he had raised the sky above the earth - about 10,000 km above for at least one version of the ancient units; not a bad value for the size of the earth). But deceased pharaohs could join the stars (with shafts provide in some tombs and pyramids for them to do so), so that star formation continued down to historic times. In the case of Cheops' pyramid, those shafts point toward Thuban (the pole star at time of construction) and Epsilon Ori (Trimble 1964). This is not to say that the Egyptians didn't know what the real sky looked like. A number of astronomical coffin lids, for instance, show Sopdet (Sirius and other stars of Canis Majoris) holding out a staff or scepter to match that of Sah (roughly Orion), though what we call Orion's belt was for them a crown, and his body was made of Beta Ori plus stars of Leporis.

Moving in the direction of serious astrology, the Chinese from at least 100 BCE onward recognized changes in the heavens that they called broom stars, guest stars, and so forth. Is this also ongoing star formation? Not quite, for all of these faded in months to years, leaving the normal stars as they had been before. They were also generally regarded as ominous, and more of them are recorded just before regime changes than at other times.

And what of "The Greeks" in the usual sense of the natural philosophers who figured out that the earth was round and might well rotate rather than having the heavens circle it? Well, there were many of them, stretched out over nearly a millennium, and they did not all say the same things. Very crudely, I think we can see both possibilities. The atomist theory of the Epicureans (Leucipus, Democritus, and others) has stars and planets and all forming out of atoms in the void, colliding and aggregating, and then eventually falling apart again (uniformitarianism), while the Aristotelian universe was a single, unique entity, having only circular motions, no beginning, and no end (and so, one supposes, no current star formation), in descriptions taken from Harrison (2000).

At least from a Eurocentric point of view, the Aristotelians won when Thomas Aquinas produced a 13th century synthesis of church doctrine and Aristotelian philosophy, in which the world and all were created at a single, definite time in the past. In 1277, however it became heresy, according to Etienne Tempier, Bishop of Paris, to claim that G.d COULD not have created other worlds. Opinion then divided on

whether he could have but did not (Oresme, c. 1320-1385 to Leibniz 1646-1716) vs. actually did create other worlds, presumably at other times (Buridan and Bradwardine in the 1300's, Nicholas of Cusa in the 1400's to Thomas Digges and Giordano Bruno in the late 1500's, the last three at least favoring an infinite number of worlds).

2 Swings of the pendulum

Cusanus, with his moving earth, infinity of inhabited worlds, each a local center of gravity and everything made of the same four terrestrial substances (earth, air, fire and water) was clearly ahead of his time, and Kepler, with his three laws of planetary motion, was something like the 15th Copernican in the world (Gingerich 2004, Danielson 2006).

Against this background, it is not surprising that Kepler, Newton, and the young William Herschel (up to 1785, say) were catastrophists. In contrast, Kant, and, for what it is worth, Cotton Mather were uniformitarians. A major swing in that direction came when Herschel arranged his images of the nebulae into what he believed to be an evolutionary sequence (published in 1811), not the modern sequence, but one at least in which primordial diffuse material became stars and planets and clusters thereof.

Development of the ideas of thermodynamics caused a swing back to "long ago and far away," when the universe of stars had somehow been charged up to high temperature, from which the stars were inevitably and irreparably cooling down. Zollner, Vogel, and Pickering in the second half of the 19th century took this argument to be definitive. This view was well expressed by Newcomb and Holden in 1885, concluding with the thought that the radiation of energy must some day come to an end. Meanwhile, however, Lowell, Ritter, and Lockyer were uniformitarians, identifying the spiral nebulae, first drawn by Lord Rosse in the 1850s as the formative stages of new solar systems.

You might reasonably have supposed that Huggins's discovery that some nebulae are truly hot, diffuse gas, emitting line spectra would have encouraged a swing back to on-going star formation, since Herschel's primordial diffuse material had evidently been found. But no, said Huggins himself in 1869. The primordial material must consist of a mix of all the elements found in the sun and earth, but he had seen only about three emission lines, one of which he correctly identified as coming from hydrogen, and the other two (now known to be forbidden lines) misidentified as nitrogen and unidentified in his view. The late 19th century uniformitarians, especially Lockyer, had in mind an early version of what, promulgated by Russell, became known as the giant and dwarf theory. That is, clouds of diffuse material contracted under their own gravitation, heating up until they became very bright hot stars, and then gradually cooled, becoming fainter and redder until they faded away resembling, perhaps, Proxima Centauri. Hertzsprung, Russell, Jeans, Robert Trumpler, and the first edition of the classic text by Russell, Dugan, and Stewart (1926) endorsed this scenario.

It was the consideration of energy sources and time scales that caused the last, firm swing back to catastrophism for star formation. The Aquinian synthesis had

allowed only the thousands of years implicit in the Old Testament begats for the lifetime of the sun (and even a coal fire could have lasted that long). Written records of several cultures and some oral traditions like that of the Maori, are consistent with that sort of duration. When the geologists (to whom the names uniformitarian and catastrophism really belong) came along, they insisted on many millions of years for the earth to cool, the oceans to build up to their present salinity, and for the laying down of very deep layers of sedimentary strata. Hutton and Lyell are best known today, and their writings span roughly 1750 to 1850 (Baxter 2003). Initially it seemed that physics and astronomy were rising up to meet them, with the idea that gravitational contraction and/or accretion could keep the stars shining for at least tens of millions of years. It is customary to credit this to Kelvin and Helmholtz, though Julius Robert Mayer and James Waterston wrote it first (and had their papers rejected).

But the geologists and the evolutionary paleontologists were soon knocking on the door again, demanding billions of years for their process. By around 1900, Simon Newcomb and others were saying that the source of solar and stellar energy was the most important unsolved problem in astrophysics. The story of how Einstein's $E=mc^2$, measurements of atomic masses, early quantum mechanics and so forth came together to spell out "subatomic energy" is too long to tell here. But with billions of years available and something like the giant and dwarf theory still in mind, "long ago and far away" seemed reasonable to Eddington (1926).

And then, as part of the general progress in astronomical telescopes and their detectors and users, came Edwin Hubble with observational support for an expanding universe in which conditions must certainly have been very different a few billions of years in the past. Hmm, mused many. The earth is a couple of billion years old; the sun and stars can be a couple of billion years old; and the universe has anyhow changed enormously in a couple of billion years. If many things are the same age, probably everything is the same age, and star formation happened when conditions were very different.

The confusing possibility that long ago meant more like 10^{12-13} yr than 10^{8-9} yr is explored in Elmegreen's contribution to this symposium and is largely associated with the name of James Jeans. His view jibed nicely with the giant-dwarf hypothesis providing that the energy source as stars cooled, dimmed, and lost mass downward along the main sequence was complete annihilation of matter rather than mere transformation of the elements. The shorter time scale and transformation was, I think, always the majority view.

3 A sort of dark age

Emblematic of this period, I think, is the revised 1938 edition of Russell, Dugan & Stewart, in which the previous correct suggestion of on-going star formation has been removed to say long, ago, when conditions were very different. Baker, revising a much earlier text by Newcomb did more or less the same thing. Here follow some of my favorite quotes from this medieval period:

Lindblad (1934) recapitulated his earlier suggestion that the present state of high angular momentum of the galactic disk may have resulted from an inelastic encounter of two systems, which inaugurated the present phase (10^{10} yr) during which the system has always been composed essentially of stars. Atkinson (1936) dealing with the problem of bright stars says of their being made anew from some diffuse material that consists of nearly pure hydrogen that the idea is NOT very attractive. He prefers that they rely on a much more generous source of energy than synthesis of heavy elements.

Bok (1936) said that it is tempting to place the origins of stars and stellar systems at the epoch of this catastrophe, 3×10^9 years ago. Goldberg and Aller (1943) worry that "we do not know what keeps the red giants and highly luminous blue stars running". Bok and Bok (1945), concluded that the galactic clusters are a vanishing species that will have disappeared a hundred cosmic years from now, and cannot be built up again, and explain that there are several reasons most astronomers are reluctant to admit that stars are still being born. Notice that these three had careers that continued to flourish after WWII (indeed I knew them all), and all changed their minds.

Russell as late as 1948 felt the need to invoke some sort of pre-stellar matter which enabled the brightest stars to survive until relatively recently when they started nucleosynthesis along the lines indicated by Bethe (1939).

A last flicker of this non-uniformitarianism appears in Greenstein (1951) where he concludes that differential galactic rotation and peculiar motions of the gas (still just HII and interstellar absorption lines in stellar spectra) are too large to permit gas condensing into stars, so that neither condensation nor accretion can be the rule.

Accretion? Where did that come from? Well, Eddington was interested in the idea, but its development as a solution to the bright star problem was due to Hoyle and Lyttleton (1939) and is, therefore, typically called Bondi accretion or occasionally Bondi-Hoyle accretion (yes there are relevant papers by Bondi, but later). The idea was that all stars formed long ago and were all of roughly solar mass or smaller, but from time to time, some of them found themselves in relatively dense interstellar matter and accreted enough material to raise them into the OBA regime, after which they burned out fairly quickly. The evidence? Well, massive stars (and perhaps as then seen only massive stars) were generally found in and around HII regions! And in a 9 June 1997 response to a query from me, Hoyle responded that in 1939 "the astronomical world did not believe in an interstellar medium containing hydrogen." Not quite true, of course, since the stationary lines in binary spectra included the Balmer lines, but indeed the discovery of obviously cold HI from its 21 cm emission was a whole world war and technological revolution into the future. In the same letter Hoyle goes on to explain that, in more recent years, in connection with the quasi-steady-state model of the universe, he has come to feel that star formation (of small objects which might later merge or accrete) was probably concentrated in the last bounce epoch once again "long ago and far away."

The last astronomers to hold by a single epoque of star formation appear to have been Gerard de Vaucouleurs (placing it at the coasting phase of a universe with cosmological constant in 1957) and David Layzer situating it in a cold big bang in 1964.

Ideas of pre-galactic stars, lagging cores, and so forth persisted somewhat past the discovery of the CMB.

4 Ad astra per aspera

The stories of the discovery of the various cold phases of the interstellar medium and Lyman Spitzer's post-war contributions to star formation theory belong to Bruce Elemegreen, but I have one further item arising from another of my letter queries, this one to Spitzer, bringing a pair of responses dated Nov. 26 and Dec. 10 1996. In the former he explains:

My keen interest in this problem dates from 1939, when I was a post-doctoral fellow at Harvard. The Bethe papers on stellar energy generation which appeared at that times (sic) indicated (at least to Martin Schwarzschild and me) that supergiant stars must be younger than any likely age for the Galaxy. In addition, the localized occurrence of such stars in the dusty clouds of spiral galaxies suggested that these clouds were the stellar birthplace. The observed absence of supergiants from globular and elliptical systems was then a natural theoretical consequence of the dynamical structure of such systems.

In 1939 I described these ideas in a talk at Harvard. Later that year, I submitted to Ap.J. a paper in which these theoretical suggestions provided me an introduction to a detailed discussion of certain dynamical processes in the interstellar medium. Several astronomers objected to this introduction as too speculative, and, much to my regret, the paper was published without this introduction.

He goes on to note that the original introduction has been printed in a book of his selected writings and offers to answer other questions. Naturally I immediately asked who had been the objectors whose carping resulted in the paper being published (in 1941) in expurgated form. Expurgated was his word, but Spitzer (who signed that hand-written note just "Lyman") went on to say that one of the people concerned was still very much alive. Thus he was unwilling to reveal his (of course!) name - the information might be regarded as derogatory. The only name I could come up with (given the context of the previous section) was Greenstein. Asked in person, he denied having been involved in the event, by then nearly 60 years before, and it is now too late to ask Spitzer again. One of the conference participants suggested Whipple as another (also Harvard) possibility. The second note also pointed out that, as late as December 1944, in a talk at an AAS meeting at Columbia, Baade did not accept the youth of Population I stars (a point also made in the Osterbrock biography of Baade). Baade's distinction between Population I and Population II was based on the appearance of their HR diagrams and on the locations of the stars.

5 The rebirth of stellar birth processes

Because there was a war threatening and soon in process, the contributions from 1938–1945 are somewhat disjoint. Ambartsumyan (1938) was probably first, saying that stellar associations had dynamical lifetimes much less than a billion years. He

concluded, however, that they had formed from very dense "pre-stellar" material, rather than by contraction of diffuse matter and so came before, rather than after, the nebulae around them. He later held to the same process for planetary nebulae and for diffuse matter associated with active galactic nuclei. Unsöld said firmly (1944) "dass solche Sterne (meaning OB main sequence stars) heute noch fortlaufend neu gebildet werden," and von Weizs̈acker (1947) laid down criteria for recognizing young stars all of which still obtain.

Over the next few years, ongoing star formation from diffuse material became the new paradigm, aided and abetted by Joy's (1945) T Tauri stars, recognized as pre-main sequence by Herbig (1953) who added the more massive Ae/Be stars (1960), Bok-Reilly (1947) globules, and an independent study of expanding associations by Blaauw (1952). In addition to the pioneers, Schwarzschild, Spitzer, and Wildt (1951), most of the famous names - Whipple, Bok, Russell, van de Hulst, Menzel, Baade, Aller, Oort and all were on the "right" side by about 1954.

6 Some parting and peripheral thoughts

There have, of course, also been thoughts on star formation by non-astronomers. My favorite comes from Huckleberry Finn as transcribed by Mark Twain, "Jim allowed they was made... but I judged it would have took too long to make so many." The late Chazzan, Philip Moddel (b. Poznan 1910, d. Southern California) was of the opinion that this time was actually infinite, the number of stars therefore also infinite, and the maker closely akin to the G.d of Section 1. Somewhere in between comes Sir John Dudley Gibbs Medley (b. Oxford, 1891, d. Australia, 1962) who had not been identified when I quoted his 1943 poem in Trimble (1997). It is too long to reproduce complete here, but a couple of key concepts say:

"Think that, provided you will wait
Your nebula is Real Estate?
Watch as the rolling aeons pass
New worlds emerging from the gas;
Watch as the brightness slowly clots
To eligible building lots."

Remarkably close to the modern view considering the date of its composition. Also remarkably close to hand was the identification of the author. Sir John (who signed the poem JDGM and who was remembered by a 1943 Observatory editor as from Melbourne) was actually still chancellor of the University of Melbourne a few years later, when the late Frank Kerr (long director of the Astronomy Program of the University of Maryland, where I spent half of each of 30 years) was a student there.

More of the serious and frivolous aspects of the history of star formation are discussed in Trimble (1997, 2007), with many more references, and also a final thought in the form of three warnings: To the Theorists: The Observers are Watching You. To the Observers: The Theorists are Watching you. And to Both: The Historians are Watching you.

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Note added in manuscript: Coates (2008), in an article focusing on linguistic aspects of the star of Bethlehem, refers to another astrological tradition that a new star appeared at every birth, or perhaps just at every royal birth ("nova stella, novus rex" in Kepler's words), which is mentioned also in Frazer's Golden Bough.

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